Differential cross-section measurements of Higgs boson production in the $H \to \tau^+\tau^-$ decay channel with the ATLAS detector

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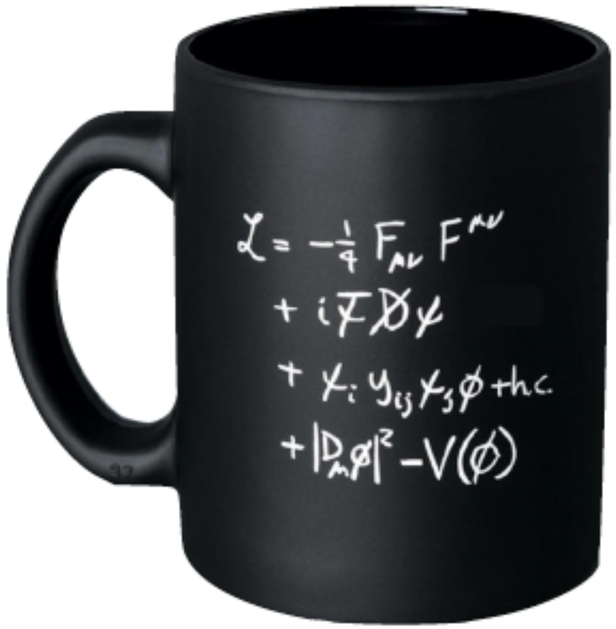
Differential cross-section measurements of Higgs boson production in the $H \to \tau^+\tau^-$ decay channel in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

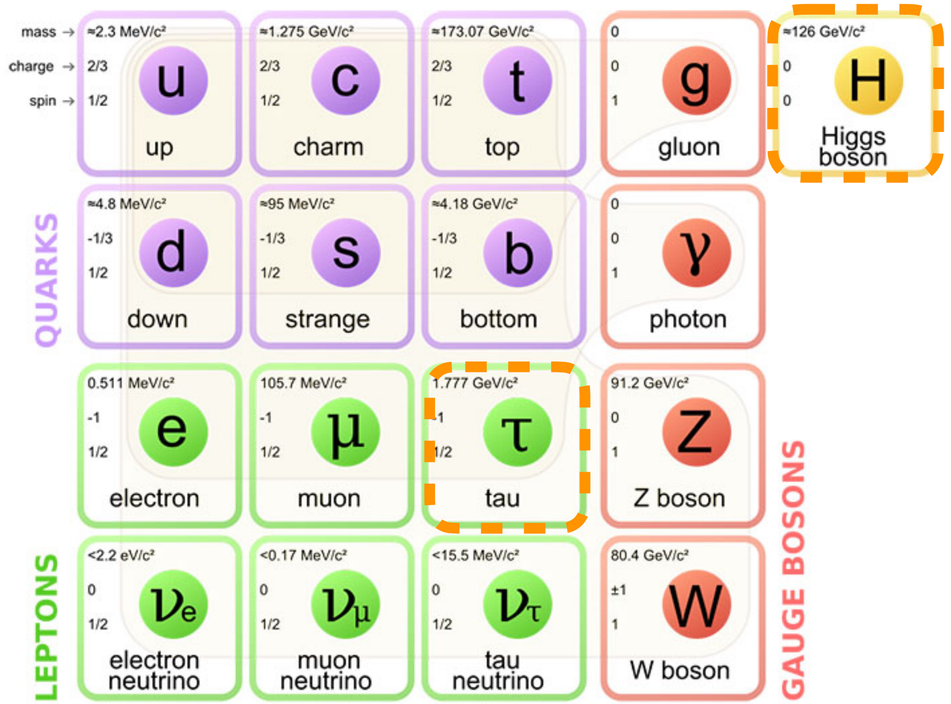
The ATLAS Collaboration

Differential measurements of Higgs boson production in the τ-lepton-pair decay channel are presented in the gluon fusion, vector-boson fusion (VBF), VH and $t\bar{t}H$ associated production modes, with particular focus on the VBF production mode. The data used to perform the measurements correspond to 140 fb^{-1} of proton–proton collisions collected by the ATLAS experiment at the LHC. Two methods are used to perform the measurements: the *Simplified Template Cross-Section* (STXS) approach and an *Unfolded Fiducial Differential* measurement considering only the VBF phase space. For the STXS measurement, events are categorized by their production mode and kinematic properties such as the Higgs boson's transverse momentum ($p_{\mathrm{T}}^{\mathrm{H}}$), the number of jets produced in association with the Higgs boson, or the invariant mass of the two leading jets (m_{jj}). For the VBF production mode, the ratio of the measured cross-section to the Standard Model prediction for $m_{jj} > 1.5$ TeV and $p_{\mathrm{T}}^{\mathrm{H}} > 200$ GeV ($p_{\mathrm{T}}^{\mathrm{H}} < 200$ GeV) is $1.29^{+0.39}_{-0.34}$ ($0.12^{+0.34}_{-0.33}$). This is the first VBF measurement for the higher-$p_{\mathrm{T}}^{\mathrm{H}}$ criteria, and the most precise for the lower-$p_{\mathrm{T}}^{\mathrm{H}}$ criteria. The *fiducial* cross-section measurements, which only consider the kinematic properties of the event, are performed as functions of variables characterizing the VBF topology, such as the signed $\Delta\phi_{jj}$ between the two leading jets. The measurements have a precision of 30%–50% and agree well with the Standard Model predictions. These results are interpreted in the SMEFT framework, and place the strongest constraints to date on the CP-odd Wilson coefficient $c_{H\tilde{W}}$.

Standard Model of Particle Physics

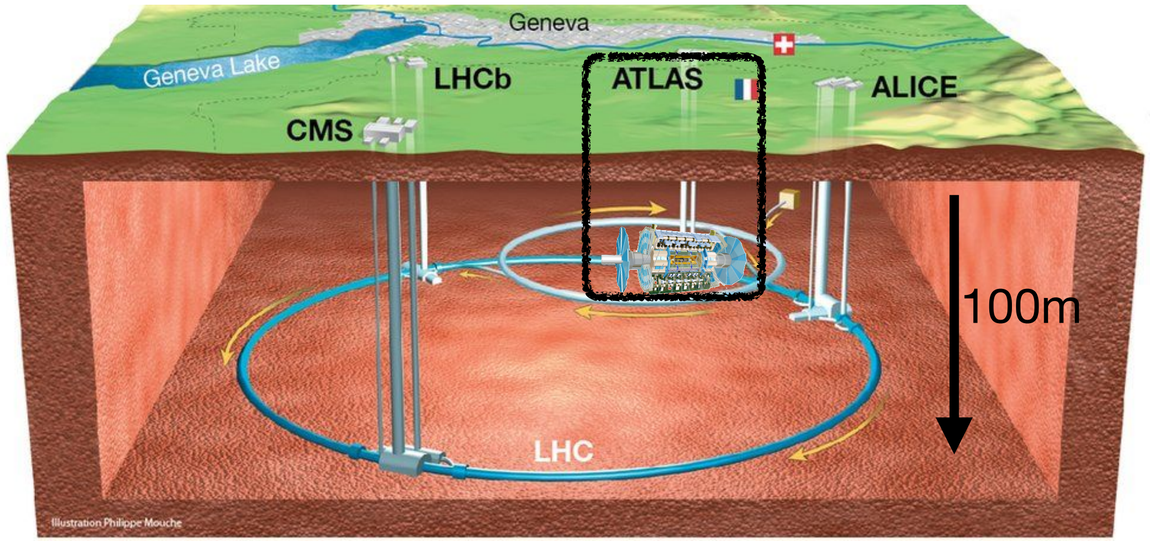
Current state-of-the-art understanding of the fundamental particles of Nature and their interactions

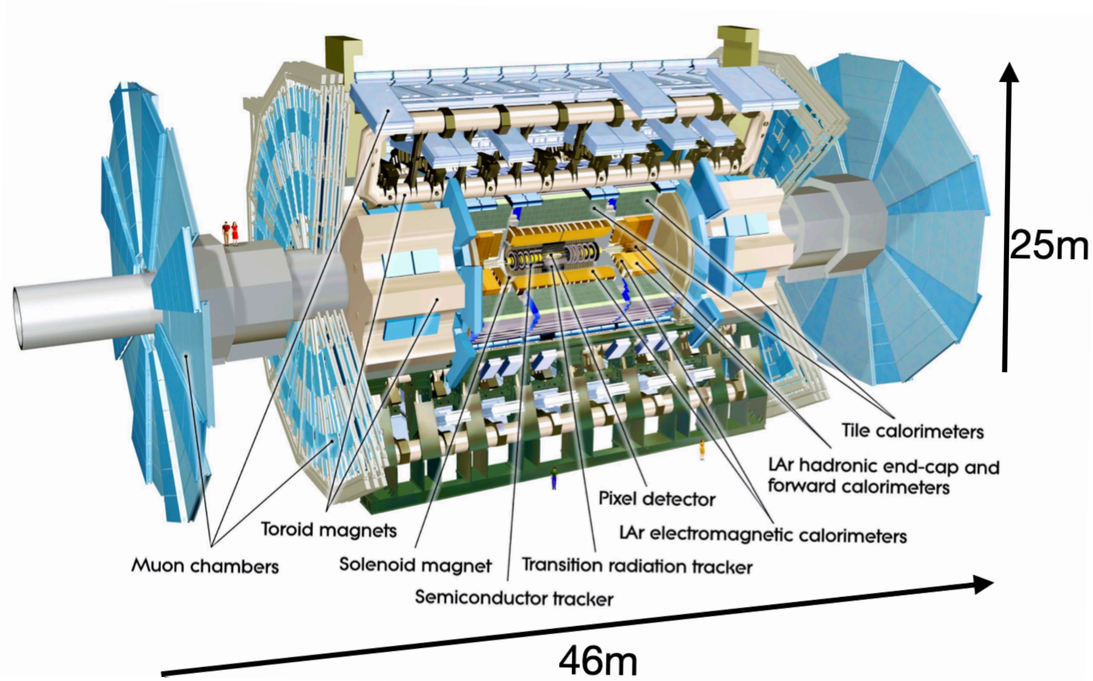




- Consistent with all observations made in laboratory experiments, except gravity.
- All particles predicted by the Standard Model (SM) have been observed since **the Higgs boson** was found at the CERN **Large Hadron Collider (LHC) in 2012.**
- Some crucial astronomical phenomena are not described (e.g. dark energy, dark matter, Baryon/Anti-Baryon asymmetry).

LHC & ATLAS Detector

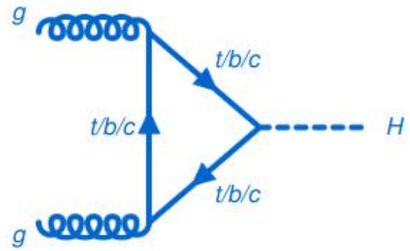
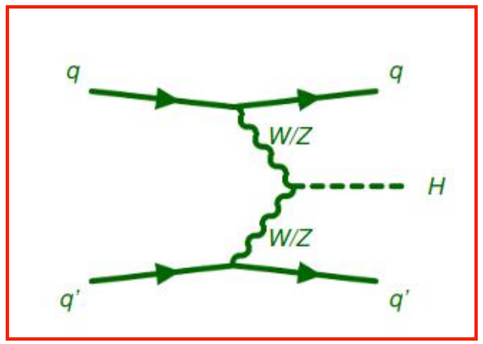
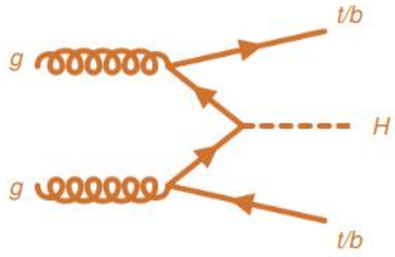
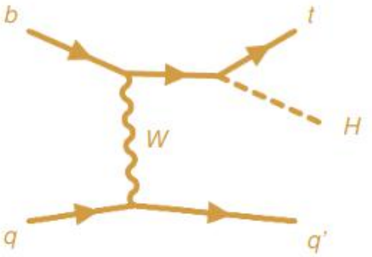




- World's largest and most powerful particle accelerator
- 27 km ring of superconducting magnets
- protons are accelerated and collided at **centre-of-mass energy** ($\sqrt{s}$) of 13 TeV in Run 2 (2015 - 2018).
- Weight: 7000 tonnes
- Detects individual particles (e.g. e, μ, γ and jets) created in the more than one billion proton-proton collisions per second.
- Records the trajectory, momentum and energy of particles

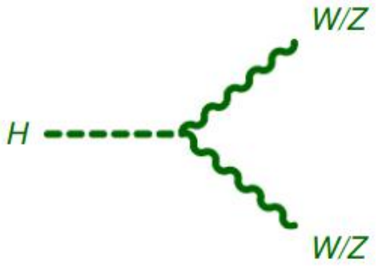
Higgs Boson Production at the LHC

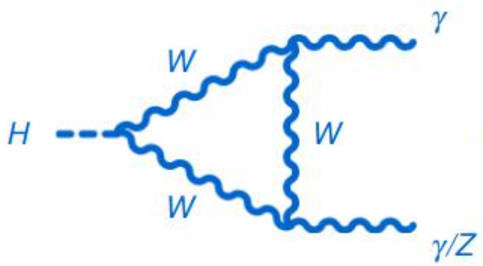
- **The Higgs boson** gives mass to the elementary particles through **the Higgs mechanism.**

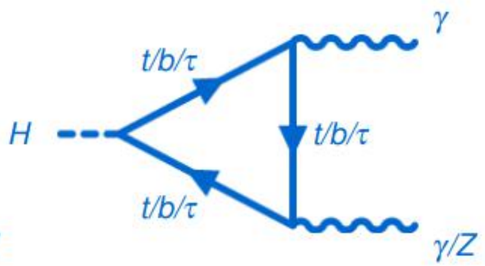
Gluon-gluon fusion (ggF)	Vector boson fusion (VBF)	Vector boson associated production (VH)	Top pair associated production (ttH)	Single top associated production (tH)
				
Relative contribution for $\sqrt{s} = 13$ TeV: 87%	7%	4%	1%	<1%

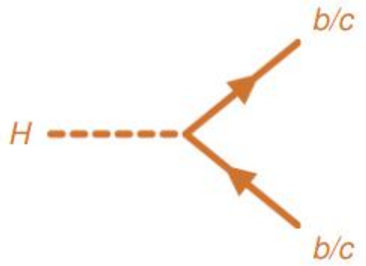
Higgs Boson Decays

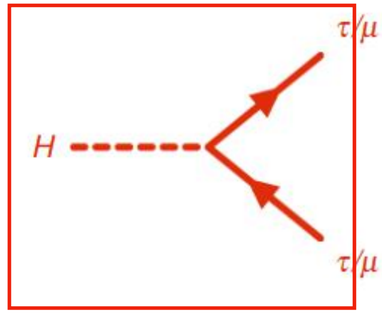
- Branching ratio is the probability that the Higgs boson decays to a certain final state.











Branching Ratio

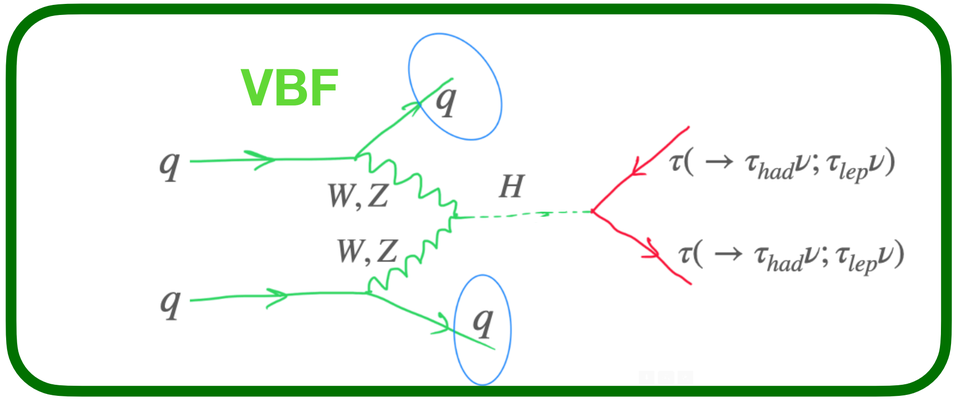
22% (WW)/3% (ZZ)

0.2% ($\gamma\gamma$)/0.2% ($Z\gamma$)

58% (bb)/2.9% (cc)

6% ($\tau\tau$)/0.02% ($\mu\mu$)

$H \rightarrow \tau\tau$ Analysis

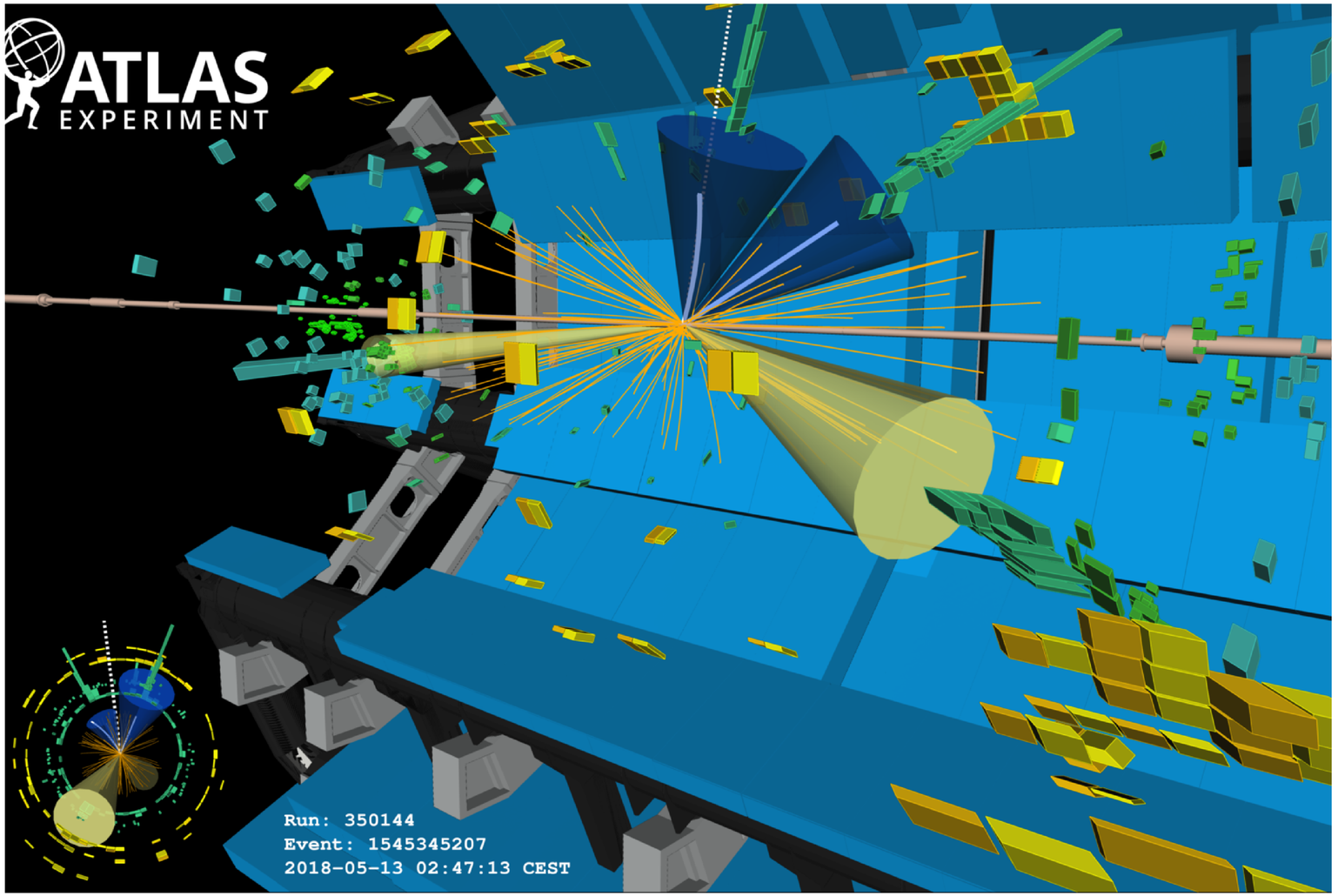


- Measurements of Higgs boson production are **crucial tests of the SM**.

- Attractive features of the $\tau\tau$ final state:

  - Sizeable branching ratio - largest of Higgs boson decays to leptons

  - Comparably distinctive signature



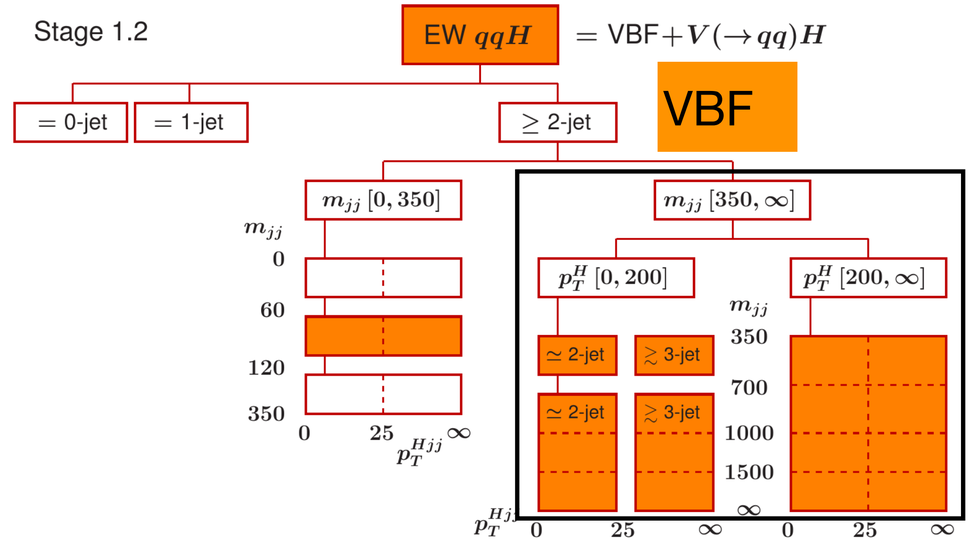
ATLAS $H \rightarrow \tau\tau$ Analysis

Cross-section is a measure for the probability to produce the Higgs boson in proton-proton collisions

Production cross-section measurements

Measurements per production mode

- Individual cross-sections for ggF, VBF, VH and ttH
- Further subdivide into kinematic categories



Differential cross-section measurement

- Measurements as function of some interesting observables (e.g. sensitive to potential new physics)
- example observable: $\Delta\phi_{jj}^{\text{signed}}$, very interesting because it is sensitive to charge-parity (CP) violation

Signal and Background

Signal signatures:

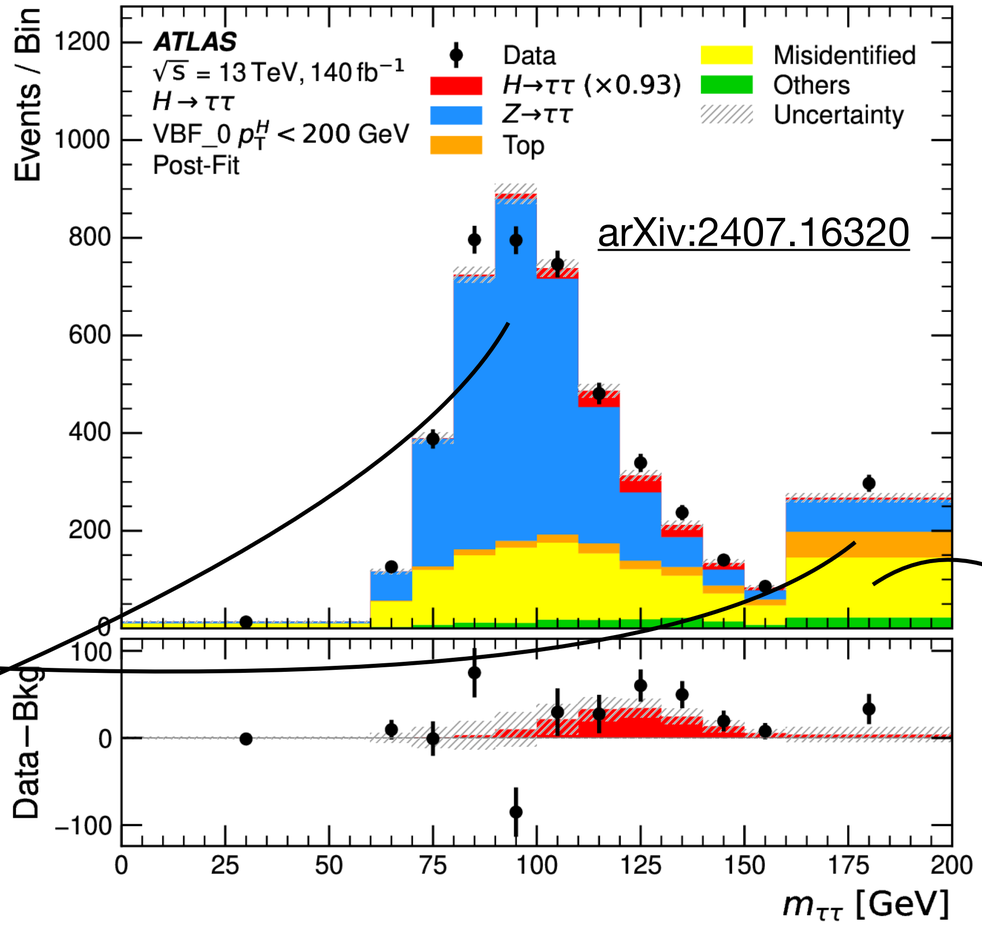
- Visible products of τ decays
- Invisible neutrinos from τ decays, reconstructed based on momentum conservation in transverse plane.
- Two Hadronic jets for VBF production

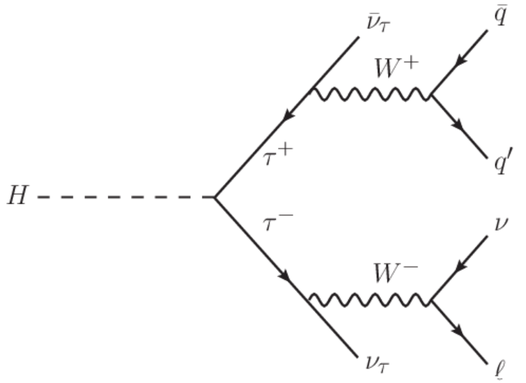
Top and other backgrounds

- Estimated using Monte Carlo simulations.

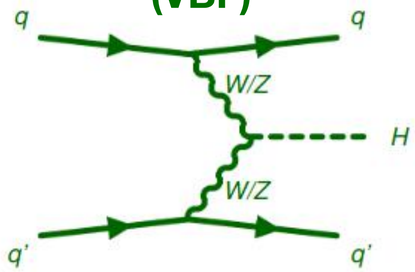
$Z \to \tau\tau$ background

- $Z \to \tau\tau$ estimated by Monte Carlo simulation





Vector Boson Fusion (VBF)

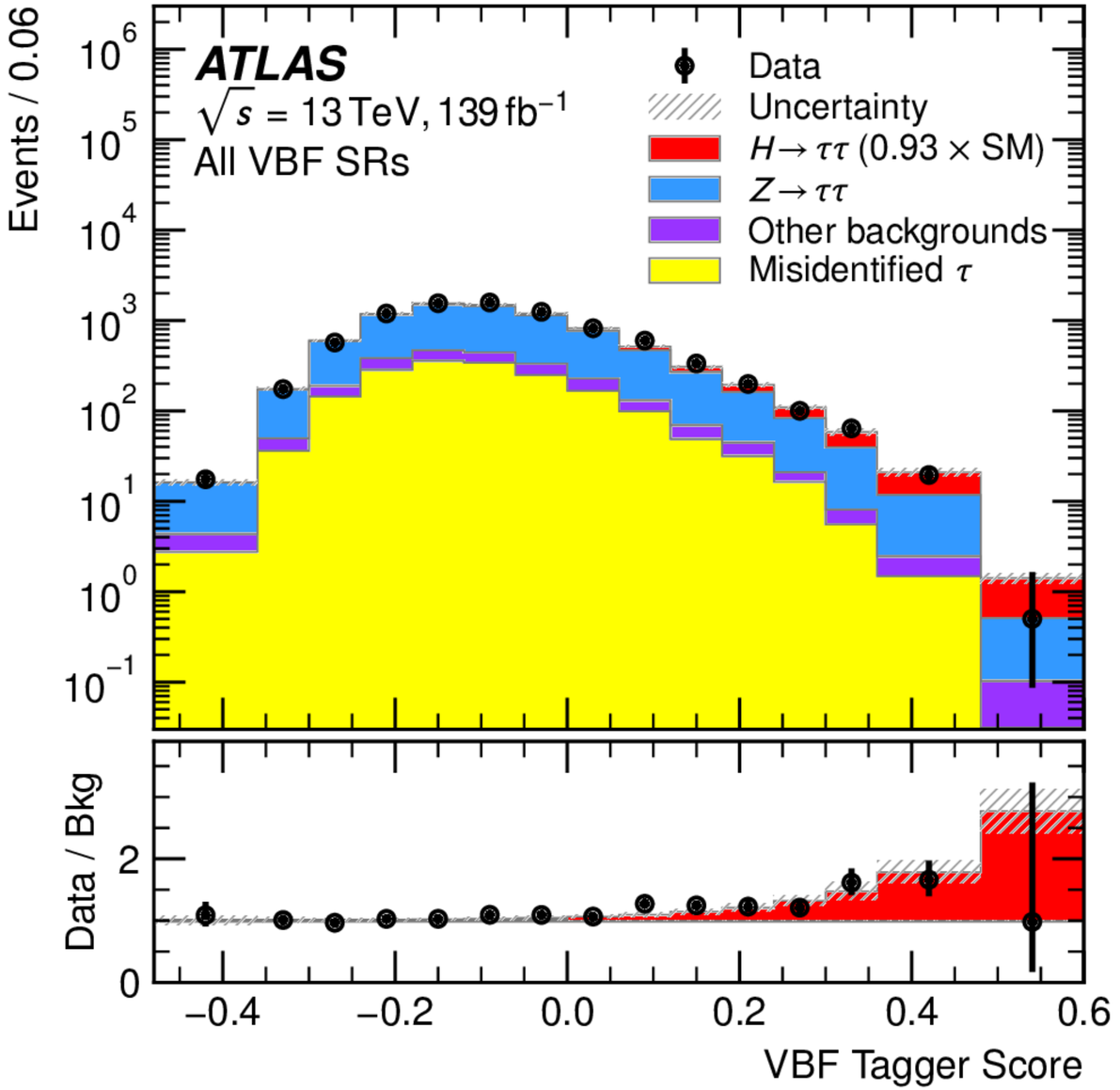


Misidentified τ backgrounds:

- Data-driven technique is used to estimate this background.

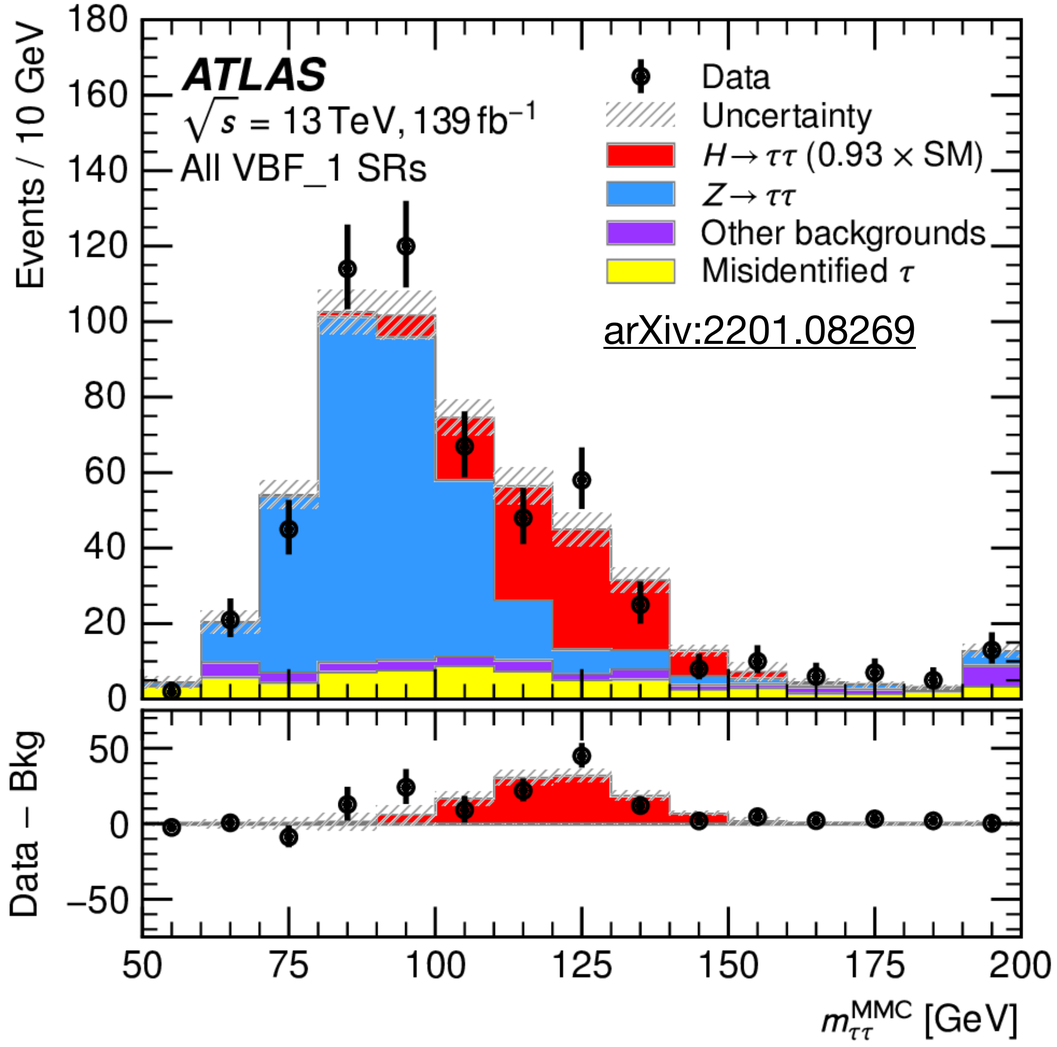
VBF Categorisation

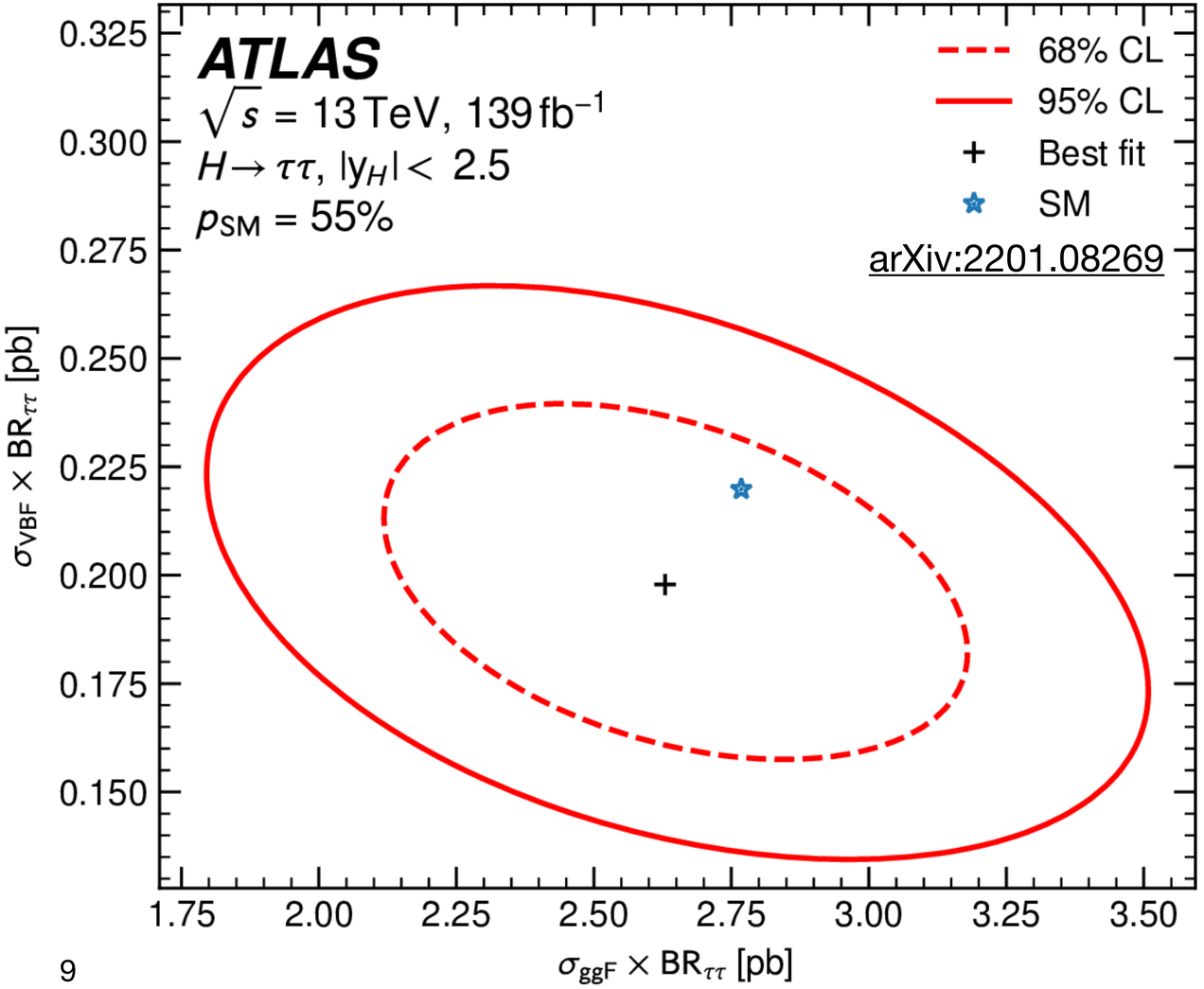
- Machine learning (Boosted Decision Tree) is used to separate VBF $H \to \tau\tau$ signal from backgrounds.



Statistical Analysis

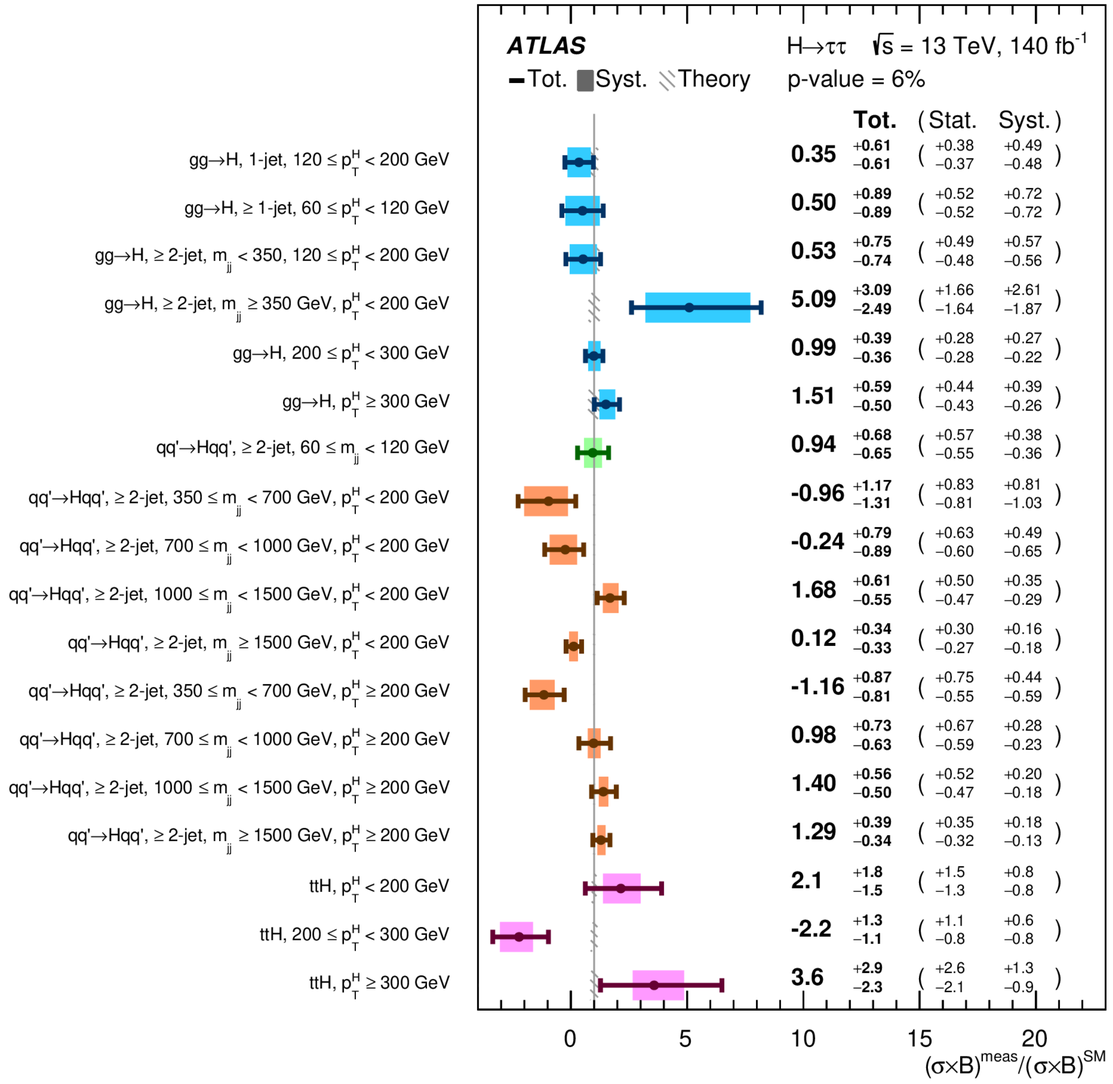
- Binned maximum likelihood fit is performed to determine central values and uncertainties of cross-sections.



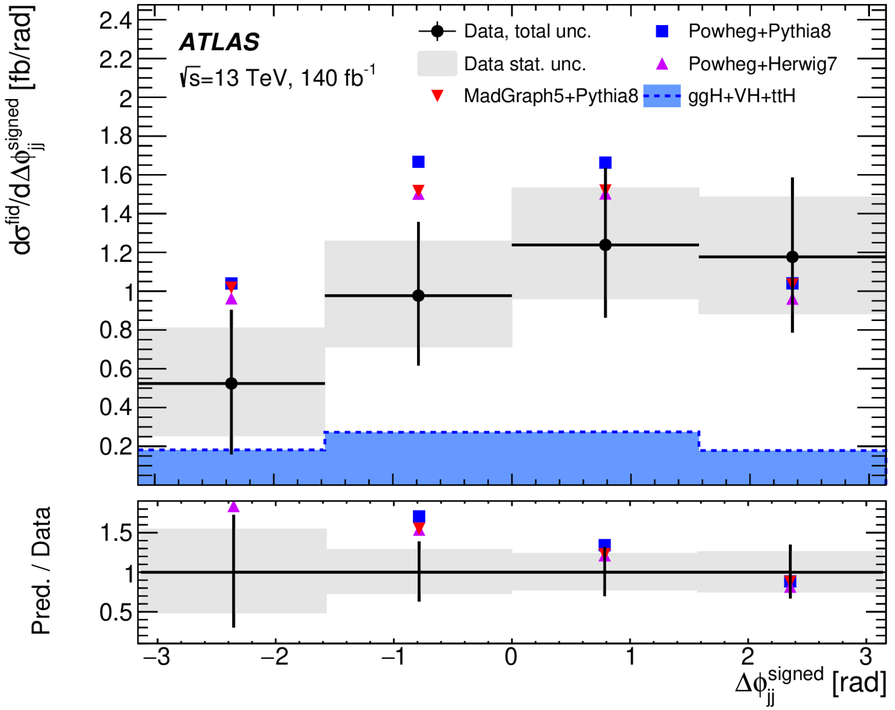


Results & Conclusions

Cross-sections for kinematic categories



Differential fiducial measurements



- Results are consistent with the SM predictions. Similar results are found in other decay modes and by the CMS collaboration.

- Higgs to $\tau\tau$ decay channel is particularly sensitive to VBF production and for high transverse momenta.

- No signs of the CP violation have been found.

Thank you!